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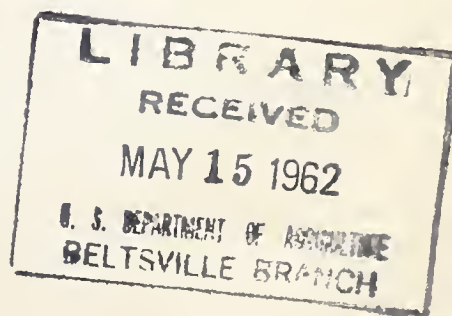
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THE STORY OF CORN



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Growth Through Agricultural Progress

Front cover photo: Corn tassel.

THE STORY OF CORN

By G. F. Sprague¹

The term "corn" is applied to various crops in different parts of the World, but in the United States it is the term in general use for the species Zea mays. Corn and its closest living relatives are indigenous to the Americas. The origin of corn involves speculations beyond the scope of this report. We shall be content with the acknowledgment that domesticating this crop and developing it to a high level of productivity was the plant breeding accomplishment of the American Indian.

Corn was a major food crop of the Indians when the first colonists arrived. It was essential not only to the survival of the first settlers but also to those who migrated Westward. It has been important in the agricultural revolution that has taken place in the last 100 years. Thus the history of the United States is closely associated with corn and its development.

When the first colonists arrived the geographic distribution of corn culture was essentially the same as today. There have been substantial increases in acreage, however, primarily in the area now known as the Corn Belt. In some other areas the increase in acreage may have been much less than commonly supposed. It is recorded that the English destroyed more than a million acres of corn belonging to the Seneca Indians in 1680 in what is now New York State. If these figures are correct this was a much larger acreage than is planted to corn in that State at present.

Corn was the preferred crop of the early settlers because of the ease of cultivation and harvest, the large returns in terms of seed planted, and its suitability as both a food and a feed crop. Corn continued to be important in the westward migration. As the settlers passed the subsistence phase, extensive feeding of livestock began. Cattle and hogs were driven back across the Alleghenies to supply demands of the increasing population along the Atlantic seaboard. Thus indirectly, corn stimulated the progress of invention and the

establishment of the necessary systems of transportation.

The extent of the agricultural revolution can be illustrated by the changes in pattern of corn culture. Corn culture, as practiced by the Indians, was entirely a hand operation. The ground was prepared by crude bone or stone hand implements; the corn was planted with a stick and tended and harvested by hand. Today, hand operations have been eliminated. Soil preparation, planting, cultivating, and harvesting are now completely mechanized.

Even though the Indian's system of corn culture was primitive as judged by present standards, his contributions were great. Current planting dates, and spacings and maturity of types grown follow the general pattern established by the Indians. They had developed adapted types for each area of the United States where corn is now of importance. Within each of these areas a diversity of types was available for direct utilization and subsequent improvement by the settlers.

Along the Atlantic Seaboard two corn types predominated. One of these was an early flint, undoubtedly similar to the present-day New England flints. The second was an extremely rough, deep-kerneled dent type, known as gourd seed. These two types were often grown in association and the Corn Belt Dents are assumed to have been derived, by selection, from such crosses.

Corn breeding has gone through three rather distinct phases. These are mass selection, ear-to-row breeding, and finally inbreeding and hybridization. Mass selection, as commonly practiced, involved selecting ears on the basis of some desirability standard, followed by the compositing of such ears as seed to plant the succeeding crop. This method of breeding undoubtedly originated with the beginning of domestication of the corn plant. Critical data illustrating the effectiveness of this breeding system are almost completely

¹Agronomist, Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture, Plant Industry Station, Beltsville, Md.

lacking since neither the U.S. Department of Agriculture nor the land-grant college system had been established when this breeding method was used most effectively.

Intercrossing of the gourd seed and Northern flint types with varying percentages of these parental types in the derivatives account for the variation in the Corn Belt types. This group of varieties was uniform in only one characteristic, the possession of a dented kernel. For all other attributes--plant height, maturity, ear size and shape, kernel and cob coloration--they were and are quite diverse. Prolific types became predominant in the southeastern areas and single-eared types in the Corn Belt and northward. This may well have been due to a difference in production hazards in the two areas. Little information is available on the origin or relative merits of varieties developed and used during this early period. Many of the varietal types of importance in the Corn Belt, before their replacement by hybrids, were originated after 1850. For the most part these varieties were developed by interested farmers rather than by public institutions.

A score card for judging corn was prepared by Orange Judd for the Illinois State Fair of 1891. The idea was quickly adopted and for a period of years Corn Shows were the vogue. Winning awards at State and world fairs brought such varieties as Reid, Leaming, and Johnson County White into prominence. Valuable prizes were awarded for the best single ears and the best 10-ear samples. Winning single-ear entries sold for as much as \$250.

Gradually it came to be appreciated that a prize-winning sample was not a good measure of the value of a particular variety or strain. Various experiment stations began to present data indicating the score card points were not closely related to field performance. Field trials disclosed numerous high yielding strains and these became widely disseminated. Consequently more and more emphasis came to be placed on field performance. In spite of demonstrated differences in performance many people persisted in the belief that mass selection--although it might be effective in rapidly modifying the characteristics of unadapted types--was relatively ineffective for modifying yield.

About 1896 an alternative system of breeding, known as ear-to-row, was developed. This method retained the individual plant and ear aspects of mass selection and added to these a simple form of progeny testing, each ear

being planted in a separate row. The popularity of this breeding system was short lived. It was highly effective for characters that were influenced but little by environment, such as oil and protein percentage, plant height, maturity, and leaf area. But it was much less effective for characters, such as yield, where environmental effects were large. The science of genetics was in its infancy, and it was many years before anyone began to inquire as to the cause of this different pattern of response.

The general opinion, later shown to be incorrect, that neither of these systems of breeding was effective in modifying yield caused research workers to explore and eventually accept the third breeding method: inbreeding and hybridization. A limited number of inbreeding studies were conducted about 1900. The investigators, however, were more impressed by the reduction in vigor accompanying inbreeding than by the restoration of vigor upon crossing. Consequently this early work did not lead to new developments in either theory or practice.

G. H. Shull, working at the Carnegie Institution at Cold Spring Harbor, N. Y., began studies in 1906 on the inheritance of number of kernel rows per ear in corn. This aspect of his studies was to be of limited importance. Observations on inbreeding depression, however, and the behavior of the inbred material in hybrid combinations were to provide a genetic basis for the development of hybrid corn. On the basis of his studies Shull concluded in his first report "...that in an ordinary field of corn the individuals are very complex hybrids, that the deterioration that takes place as a result of self-fertilization is due to the gradual reduction of the strain to a homozygous condition and that the object of the corn breeder should not be to find the best pure line but to find and maintain the best hybrid combination."

In a later discussion of the pure-line method he stated, "In finding the best pure lines it will be necessary to make as many self-fertilizations as practicable and to continue these year after year until the homozygous state is nearly or quite attained. Then all possible crosses are to be made among these different pure strains and the F_1 strains coming from such crosses are to be grown in an ear-to-row test, each row being the product of a different cross. After having found the right pair of pure strains for the attainment of any desired result in the way of yield or quality, the method of producing seed corn for

the general crop is a very simple though somewhat costly process."

The procedures visualized by Shull have formed the backbone of hybrid corn development. In retrospect one can wonder at the long delay from Shull's suggestion in 1910 to the commercial fact in the 1930's. Many problems, both theoretical and practical, required solution before hybrid corn was to become a commercial reality. The cost aspects, recognized by Shull, were minimized after D. F. Jones of the Connecticut Station developed the double-cross methods in 1918. Burr-Leaming, the hybrid developed by Jones, was limited in its adaptation and never became commercially important. It remained for other workers to develop better lines which were to become of importance in this new enterprise. Large numbers of lines were developed and evaluated but few had sufficient merit, as lines and in hybrid combinations, for commercial use. It has been estimated that less than 1 line per hundred tested has possibility for commercial acceptance.

A large number of important developments were made by corn breeders from 1920 to 1940. These included: (1) the improvement and development of statistical procedures and field plot design to permit the testing of large numbers and still permit the degree of precision required, (2) a measure of the relations between characteristics of the inbred and the same trait in the crossbred progeny, (3) the development of simplified techniques for evaluating combining ability of large numbers of lines, (4) the use of diallel single-cross data for predicting double-cross performance, and (5) a knowledge of the relation between level of inbreeding and hybrid performance. Each of these contributed directly to the development of commercial hybrid corn. Improvements in both theory and practice have continued to the present. Many of these developments have contributed not only to hybrid corn but also to the use of heterosis in many other organisms.

Most of the public corn programs giving emphasis to inbreeding and hybridization were organized in the early 1920's. Several of the major hybrid corn companies came into existence and began their breeding programs at about this same time. When the first trickle of hybrid seed reached the farmer about 1930 no one could foresee the ultimate importance of hybrid corn. Some thought

that only a small fraction of the corn acreage would ever be planted to hybrids. Others thought that most farmers might produce their own seed and a few might also produce seed for their neighbors. Special training schools were held to train interested persons in the mechanics of hybrid seed production. At that time and for several years the inbred lines and the open-pedigree hybrids, developed by the State experiment stations and the U.S. Department of Agriculture, were in extensive use. Eventually the private hybrid seed companies assumed more and more responsibility for hybrid development and thus provided public agencies with more opportunity for basic research.

In 1934 less than 1 percent of the corn acreage of the Corn Belt was planted to hybrid corn. This had increased to 52 percent in 1943 and to 86 percent in 1953. In 1961 over 96 percent of all corn planted in the United States was hybrid.

The substitution of hybrids for varieties, plus other changes in farm management practices, has had a tremendous effect on production. In the period 1928-32 (prior to large-scale use of hybrids) we grew slightly more than 100 million acres of corn per year with an average production of 2.5 billion bushels. In the period 1945-54 (when most Corn Belt acreage was planted to hybrids) corn acreage decreased to about 85 million acres per year and production rose to more than 3 billion bushels. Thus during this period corn acreage decreased by 20 percent and production increased by 20 percent. Production has risen still further since 1954.

Increases in yield alone provide an incomplete picture of the improvements that have been achieved. Hybrids are generally superior to open-pollinated varieties because of their increased resistance to insects and diseases. The first improvements were an increase in resistance to ear and stalk rots. Adequate data are not available to document these improvements. We shall use as our measure of progress, therefore, the work on the European corn borer. This destructive pest was first reported in the vicinity of Boston in 1917. At that time it was already causing serious damage to sweet corn and many truck and garden crops. By 1926, hundreds of acres of corn in Ontario, Canada, sustained a loss of over 50 percent. Comparable losses occurred in New York, New

Jersey, and the New England States in the years that followed. A special laboratory was established in Ohio in 1930 to investigate the possibilities of control by means of improved cultural practices, the introduction of parasites and predators, the use of chemical sprays, and the development of resistant types. (We shall be most concerned with the resistance phases of this program.) As the borer migrated westward a second laboratory was established at Lafayette, Ind., in 1942 and it was moved to its present location at Ankeny, Iowa, in 1949.

Well over a thousand inbred lines possessing a high degree of resistance to the first brood of the borer have been developed. Data from single crosses involving resistant parents indicate that a satisfactory level of protection has been achieved. Inbred lines that possess a high degree of resistance or tolerance to second brood infestations have also been identified. Some of these lines are in extensive commercial use. The maximum degree of protection, however, will be attained only when all four parental inbreds of a double-cross possess both types of resistance. Substantial progress has been made but this goal has not yet been achieved.

Some of the more recent hybrids possess resistance to the corn earworm and the leaf blights. Sources of resistance are available for other diseases and are being incorporated into commercially usable types. Search continues for new types of resistance to the pests mentioned and for resistance to insects and diseases that are less widely distributed or that cause less average damage.

The increase in average yield has resulted from several factors. First, there has been gradual improvement in the productivity of the hybrids grown. The first hybrids that were distributed have been replaced by more recently developed superior combinations. Second, there has been a tremendous increase in the use of chemical fertilizers.

The colonists of the New England area were introduced to the fertilization of corn by the Indian Squanto who advised the placing of two fish per hill of corn on newly cleared forest land. This practice was not suited to general use and for many years the use of farm manures and crop residues were the primary fertilization practices. It appears likely that not more than one-quarter to one-third of the potential value of farm manure was realized because of poor practices in handling and application. Thomas Jefferson is reported

to have said, "We can buy an acre of new land cheaper than we can manure an old one."

The need for fertilization varied widely and depended on the parental material, climate, topography, and farming practice. The soils of the Eastern Seaboard responded to fertilizers shortly after they were brought under cultivation, whereas the deep prairie soils of the midwest responded little until after many years of cultivation. In 1860 we used approximately 32,000 tons of commercial fertilizer. This figure had increased to 8 million tons in 1930, and close to 30 million tons in 1960. This increase in tonnage does not tell the whole story as there has also been a marked increase in mineral nutrient content.

Prior to 1940 fertilizer use was largely concentrated in States bordering the Atlantic Ocean and Gulf of Mexico. Less than 9 percent of the total fertilizer nutrients and nitrogen used were utilized in the Corn Belt. Fertilizer use has increased markedly since 1940, but this increase has not been uniform throughout the country. Fertilizer use increased nearly 10-fold in the Corn Belt area from 1940 to 1955. During the same period fertilizer use in the Southeast nearly doubled. This increased use of fertilizers has been reflected in increased yields of corn. There has also been a gradual increase in plant population accompanying the increased use of fertilizer.

Corn has a marked capacity to respond to fertilizers, particularly nitrogen. Hybrids, however, make more efficient use of applied fertilizers than do open-pollinated varieties.

The impact of mechanization on corn production has been tremendous. The "sod corn" of the early settler produced a crop of sorts the first year. Its main advantage was that it required little cultivation which left the settler free to build his house and prepare more land for the next year's crop. Ground to be planted was cross-marked and planted by hand. Cultivation was with a harrow, often homemade, and a double-shovel cultivator that cultivated only a single row. When necessary this cultivation was supplemented by hand-hoeing. Hand planting was gradually replaced by mechanical planters, at first drawn by oxen, later by horses or mules, and more recently by tractors. It has been estimated that an experienced man could plant about 4 acres of corn a day with a hand planter. A tractor mounted 4-row planter, in extensive use today, can plant in excess of 40 acres of corn per day.

Corn harvesting, as practiced by the settler, consisted in cutting the standing stalks by hand and placing them in shocks to dry. The ears were husked as the fodder was needed for livestock and the grain for food or feed. With an increase in acreage, fodder production exceeded that needed for livestock feed. When this stage was reached, harvesting of the ears from the standing stalks became a common practice. An experienced man could harvest 100 bushels per day under favorable conditions. With equally favorable conditions a modern 2-row picker can harvest 1,000 or more bushels per day. Thus for both planting and harvesting there has been at least a 10-fold increase in efficiency.

Approximately 135 hours of labor was required to produce 100 bushels of corn in 1910. As a National average in 1960, about 23 hours of labor was required to produce 100 bushels of corn. In some areas corn is now being grown with a total labor investment of less than 8 hours per 100 bushels. In addition to this gain in labor efficiency, there has been a gain in productivity due to increased timeliness of operations.

Mechanical corn harvesters have been available for many years. They have been used extensively, however, only since the development of hybrid corn. No more than 12 percent of our corn acreage was harvested by mechanical pickers in 1938. The open-pollinated varieties were susceptible to severe lodging under adverse conditions. Under such conditions the early mechanical harvesters were inefficient and left large quantities of corn in the field. The hybrids, which possess marked resistance to lodging, stimulated the utilization of mechanical equipment by farmers, and encouraged the equipment manufacturer to develop improved machines. Over 95 percent of the corn acreage in the Corn Belt was harvested mechanically by 1956. Corn production is now almost completely mechanized, which permits a greater timeliness of all field operations and a striking reduction in production costs per bushel or per acre.

Over 85 percent of the U.S. field corn crop is used for livestock feed, the remainder being processed by industry. Utilization by industry falls into three rather distinct categories: dry milling, wet milling, and fermentation. The dry millers use approximately 100 million bushels yearly to produce flour, meal, grits, and hominy. The wet millers use about 150 million bushels yearly to produce starch, oil, and gluten. Each of these

products may be used directly or subjected to chemical modification to produce several hundred special products or compounds. The main products of the fermentation industries are acetaldehyde; ethyl, butyl, and propyl alcohol; acetic, lactic, butyric, formic, fumaric, citric, caproic, caprillic, oxalic, oxygluconic, pyruvic, and succinic acids; and 2-3 butylene glycol. If one or more of these substances were used as substitutes for further modification, the list of possible products could be extended materially.

Some work is under way to improve corn for each of these outlets. It has been established that both quantity and quality of oil are controlled genetically. Strains are available that contain up to 16 percent of oil, approximately 3.5 times more than the oil content of normal corn. Fatty acid composition varies with oil percentage. Oleic and the saturated fatty acids increase with an increase in oil percentage whereas linoleic acid decreases. Increases for oleic and the saturated fatty acids follow distinctly different rates, which suggests that they are controlled by different genetic systems. The optimum oil percentage may well vary with the intended use of the crop. In industry, oil is a valuable byproduct and any increase in oil content would be desirable at today's oil prices. The desired percentage of oil in corn as a feed may vary with the class of livestock to be fed, being lower for swine than for ruminants.

The broiler industry needs a high xanthophyll source to impart the degree of skin and shank pigmentation desired by the trade. Alfalfa-leaf meal can be used but is undesirable because of the accompanying decrease in the energy value of the ration. Strains of corn have been identified that carry 60 p.p.m. of xanthophyll, which is adequate. Breeding efforts are now underway to incorporate this xanthophyll level into commercially acceptable hybrids.

Industry has need for starch having a wide range in rigidity and pasting properties. Normal starch may be chemically modified to meet these needs, but this is a far less efficient procedure than genetic modification. The possibilities of genetic modification have been amply demonstrated by the development of waxy corn. This type of corn produces starch consisting entirely of amylopectin, the branched-chain molecular form. Hybrids having this trait have been developed, and several million bushels of this type are now milled annually to meet industrial needs. Other genetic types are known that produce starch having a

high percentage of amylose, the straight-chain molecular form. Hybrids having approximately 60 percent of amylose are in limited commercial production. Experimental hybrids having 70 percent of amylose are being tested. Strains having still higher percentages of amylose are available as potential breeding stocks.

If one were to assess hybrid corn development solely in terms of increased production or the potentiality for increased industrial utilization of corn within the United States, the picture would be far from complete. The theoretical and practical developments that made commercial hybrid corn feasible have been widely adopted in areas outside the United States and also in the breeding of organisms other than corn. In some instances the practices have been adopted bodily, and in other cases modifications have been made to fit the peculiarities of the organism or the situation. A few illustrations will indicate the extent of these contributions. We shall consider first the utilization of hybrids in several areas of the world.

The techniques of hybrid corn production have been exported to many areas of the World. In some areas parental material from the United States has provided the initial seed source; in other areas the U.S. material has not been adapted, and local programs were completely dependent on their own efforts. The adoption and utilization of hybrid corn in Western Europe is an excellent illustration of the first situation. Even in Western Europe less and less dependence is being placed on U.S. material as the local breeding and testing programs become productive. At present in the Po Valley of Italy some areas have as high percentage utilization of hybrids as has the United States.

The Latin American countries provide an illustration of an area where the theory and practice of hybrid corn development was adopted but where U.S. material was not suited, and all inbreds and hybrids had to be developed from locally adapted varieties. Marked progress has been made in many of these countries, but the greatest utilization of hybrids has been achieved in Mexico and Colombia. Hybrid seed has been available in Mexico for several years. The same pattern found in the United States is being repeated. The first hybrids released were markedly superior to the open-pollinated varieties of a given area. These hybrids, in turn, are now being replaced by new higher yielding combinations.

The corn program in Colombia has been in existence for a little more than 10 years. In spite of this short period superior hybrids have been developed and are extensively used in some areas. It has been estimated that in the Cauca Valley, one of the rich agricultural areas of the World, hybrid corn is grown on 75 percent of the corn acreage. In this area, where two crops per year are possible, yields of 300 bushels per acre per year have been obtained with proper fertilization and the use of hybrid seed.

India presents still a different picture of utilization. Some of the U.S. lines can be utilized in parts of India. Similarly some lines of Mexican and Colombian origin are also useful. Some of the first hybrids which will be used on an extensive commercial scale will involve lines of Indian, Mexican, Colombian, and U.S. development. In many other areas of the World, hybrids in commercial use will involve parent lines of local development as well as lines developed in other countries.

A few examples will illustrate the contributions of corn breeding theory to the improvement of other species. The top-cross test (inbred x variety) was developed and adopted to facilitate the evaluation of large numbers of lines. The problem, which required solution, can be illustrated by the fact that if the first evaluation was to be as single-crosses, 4,950 combinations would be required to evaluate 100 lines. These same 100 lines could be evaluated as 100 top-crosses. In terms of genetic expectations the top-cross performance of a single entry is the arithmetic average of a large number of single-crosses having the inbred line or female parent in common. This procedure has its equivalent in the polycross test widely used by forage crop breeders and in sire evaluation used extensively in animal breeding.

Synthetics (populations formed by random mating among a series of inbred lines) were first studied in corn to provide additional information on heterosis. The experimental results indicated that some degree of heterosis could be retained where F_1 hybrids were not feasible. Many commercial grass and legume strains now available were produced by this process. Synthetic varieties of corn have not been grown to any extent in the United States, but they have been grown in both Mexico and Colombia. They may be important in other areas where corn programs are in early stages of development.

In the 1930's research was undertaken on the relation between degree of inbreeding of strains of corn and their performance in hybrid combinations. The results indicated that lines isolated by one generation of self-pollination performed essentially as well in hybrids as the long-time selfed derivatives of these same lines. This finding has been used extensively. The first hybrids released for production in Mexico and Colombia were made using S_1 parent lines. The commercialization of hybrid chickens, which has undergone a phenomenal expansion in recent years, was based on the same findings. Inbreeding in bisexual organisms proceeds at a much slower pace than under self-fertilization. Three generations of brother-sister matings are required to reduce average heterozygosity by 50 percent. This same reduction can be achieved by one generation in organisms where self-fertilization is feasible. Thus, if a high degree of inbreeding were required for satisfactory hybrid performance, hybrid chickens might still be a goal for the future rather than a well-established reality.

Methods were devised in 1942 to utilize data from corn single crosses to obtain estimates of genetic variances, which in turn provide a measure of the relative importance of different types of gene action involved in heterosis. This, together with related techniques developed in corn, has been very useful in evaluating the efficiency of different breeding procedures in corn and other crop plants, and in animals.

Many other instances might be cited of the contribution of corn research to breeding developments and genetic theory. These few, however, should be convincing that corn breeding research has had an impact far greater than that resulting from increased production per acre.

This story would not be complete without some speculation as to future developments. Certainly the trend of increased emphasis on basic research by the U.S. Department of Agriculture and the land-grant colleges will continue. As a part of this same trend, private industry will become increasingly important in the production and distribution of hybrid seed. Our speculation on future needs and developments, therefore, will be confined to those areas which can best be handled by public institutions. Since funds are needed for basic research, it may be well to remind ourselves that agricultural research has an average return on the investment dollar of

between 35 and 170 percent per year. In the case of hybrid corn--one of the most significant developments of the past 4 decades--the total return on research investment made during the entire period was, as of 1955, 700 percent per year.

Improvement in corn, in yielding ability, in nutritional qualities, and in value for industrial processing is certainly possible. Improvements in any of these areas will depend in large part on the research effort devoted to the solution of problems now known to require attention and to additional problems as they arise.

In considering basic research needs we shall be content to list broad areas, remembering that any basic advancements will have some measure of applicability to a wide range of organisms.

Biochemical Genetics:

It was mentioned earlier that some progress has been made in developing types with high oil, waxy starch, and an increased xanthophyll content. These results have been obtained by empirical methods. We have no adequate knowledge of the course of synthesis of oils, carbohydrates, proteins, or any other components that may have nutritional or industrial potential. Basic information on synthesis could be very helpful in increasing the efficiency of genetic control and could also provide a measure of the modification that is feasible.

We have no adequate knowledge of the mechanism by which plant roots absorb nutrients. We do know that when plants of differing genotype are grown in the same soil or culture solution one may be normal and the other exhibit typical nutrient deficiency systems. Is this difference in response due to differential absorption or differential utilization after absorption? Information on the mechanism involved may aid in increasing the efficiency of use of fertilizers.

Plants are subject to attack by various insects and diseases. Differences in resistance are known to exist. In no case, however, do we know the chemical basis for such differences. The whole area of host-parasite interactions needs detailed study.

We are making commercial use of the phenomenon of heterosis in both plants and animals, but we are not yet able to provide a completely adequate explanation in terms of either genetics or physiology.

Statistical Genetics:

Our knowledge of statistical genetics is inadequate. Progress has been made in breeding but this is a result of the large numbers handled rather than a measure of our understanding of the processes involved. We need more information on the relative importance of different type of gene action, the relative efficiency of different breeding systems in changing gene frequency, and the basis and extent of genotype-environment interactions. We have been able to make use of exotic germ plasm when such types are reasonably well adapted. We have not been able to make efficient use of such material when it is poorly adapted because of length of day response or for other reasons. Is this because of some barrier to free recombination or is some more subtle mechanism operating? This problem will require solution before the worldwide genetic variability existing in corn becomes available for general use.

It is assumed that mutations are the basis for all genetic variability. We know that various types of radiation and many chemicals are mutagenic, giving rise to new mutant forms. We do not know, however, the molecular

basis for such mutations nor can we produce a specific type of mutation at will. More information on this process would certainly lead to more precise control of breeding operations.

Pathology:

Much effort has been devoted to developing resistant types. Such resistance is often temporary because of a change in virulence in the pathogen. We have, as yet, little knowledge of the potentiality of the pathogen to undergo changes in virulence. Until such information is available, it will be impossible to devise more efficient screening techniques or to expect the development of lasting resistance.

The same general arguments apply to insect resistance. The development of resistant types appears to offer a more permanent solution than does chemical control because of the known tendency of insects to develop immunity to effective chemicals. This indicates a genetic lability of the insect pest. A knowledge of the extent of this lability when exposed to genetically resistant hosts remains to be determined.

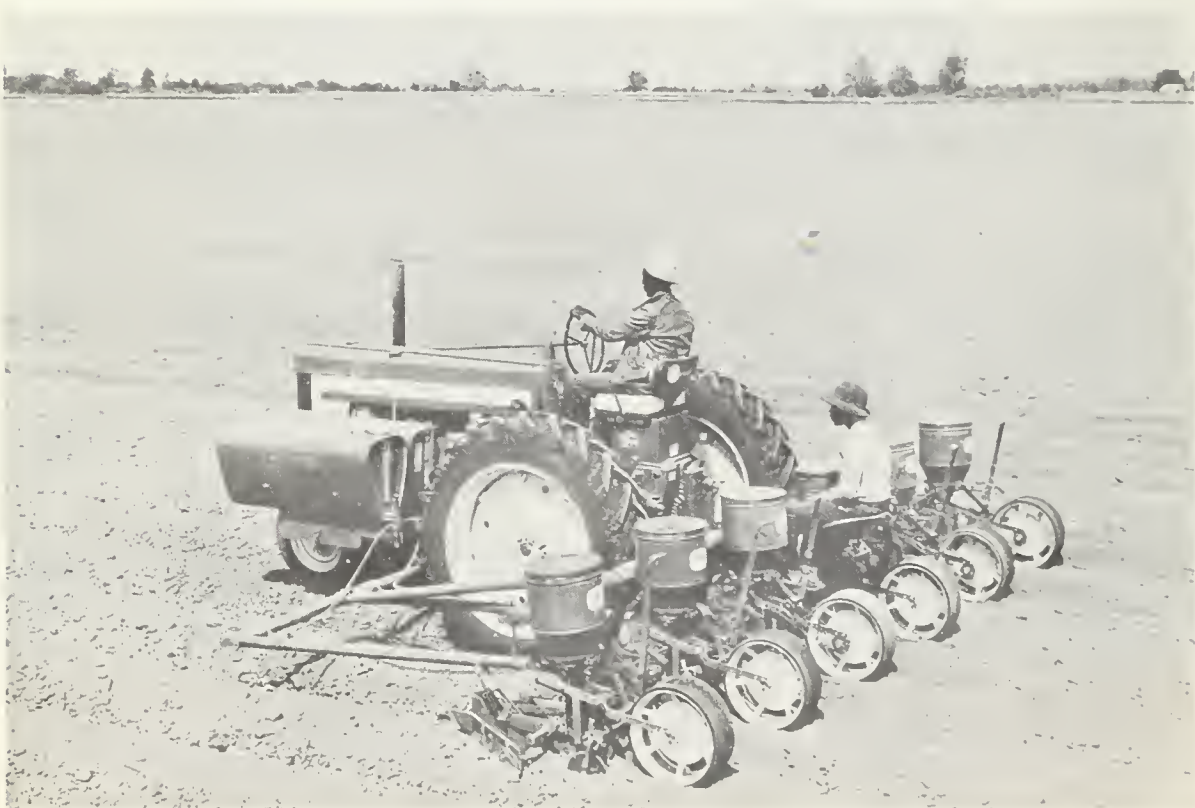
The list of problems requiring solution could be extended indefinitely. The limited work already done in these areas offers promise that more extensive and more basic research would be rewarding.



Corn types grown by Indians of the Americas.



Planting with a 2-row corn planter.



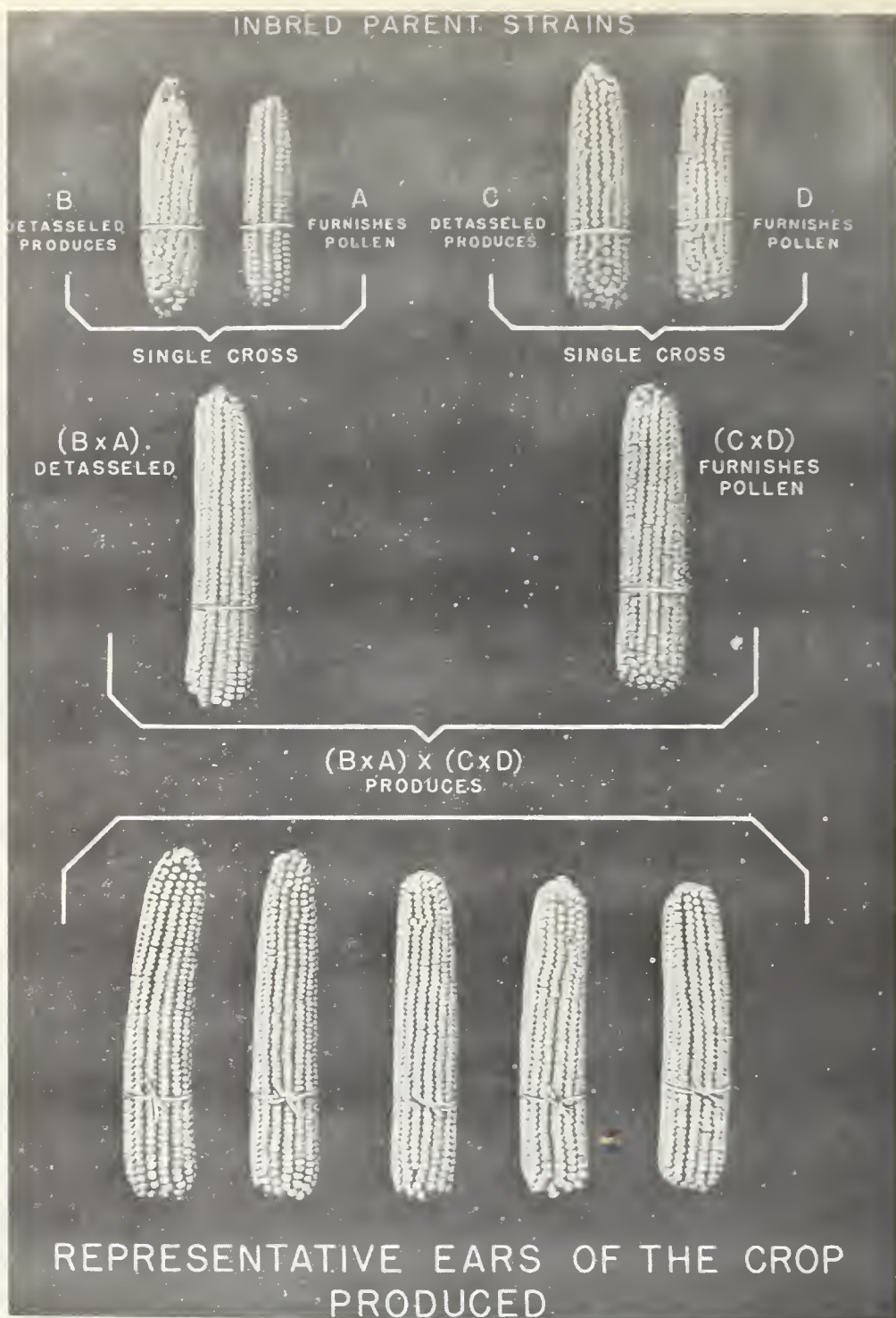
Planting with a 6-row planter.



Harvesting corn by hand. (Less than 15 percent of the crop grown for grain is now harvested in this manner.)



Harvesting with a mounted 2-row picker. (Approximately 85 percent of the crop grown for grain is harvested mechanically.)



Method of producing double-cross hybrid seed corn and representative ears of the crop produced from hybrid seed.



An isolated crossing plot for the production of hybrid seed. (The tassels have been pulled from female parent plants. The tassels were left on the male rows to supply pollen for the entire field.)



Weeds in corn can be effectively controlled through use of several herbicides.



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A line of corn susceptible to leaf feeding by the first brood of the European corn borer.



A line of corn resistant to leaf feeding by the first brood of the European corn borer.

